Section 5
Thermal Control System Overview

5.1 Introduction

Throughout the life of the Space Station, eperiments and equipment inside the modules are generating heat that must be removed. Outside the modules, experiments and equipment must be protected from the environment in low Earth orbit. ***The purpose of the Thermal Control System (TCS) is to maintain Space Station equipment and payloads within their required temperature ranges.***

This section provides an overview of the Space Station TCS. The components and general operational capabilities of the TCS are presented, as well as the various interfaces to other Space Station systems.

5.2 Objectives

After completing this section, you should be able to

- Compare and contrast the major capabilities performed by the United States Orbital Segment (USOS) and Russian Orbital Segment (ROS) TCS.
- Identify the functions of each of the TCS subsystems.
- Explain the redundancy scheme for Internal and External TCS loops and the operational consequences of loss of those major functions.

5.3 TCS Architecture

In order to understand how the thermal control process takes place, a look at the overall Space Station TCS architecture is necessary. As shown in Figure 5-1, the Space Station TCS is composed of Passive and Active thermal control systems.

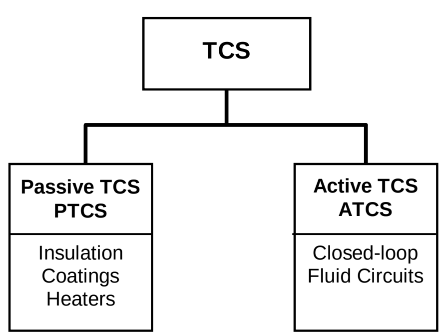


Figure 5-1. Space Station TCS architecture

The Passive Thermal Control System (PTCS) consists of insulation, coatings, and heaters. Its components generally have few operational requirements and require low maintenance. PTCS components are also less complex and easier to implement.

The Active Thermal Control System (ATCS) uses a mechanically-pumped fluid to perform heat transfer. Although this approach is more complex, the ATCS handles much greater heat loads and provides a higher degree of control over how the heat loads are managed.

The USOS and ROS use this same architecture, modified to meet the needs of individual elements. ROS TCS is very similar in design to the Mir space station and functionally similar to USOS TCS. The main difference is that each module has its own internal and external TCS (i.e., the modules do not share an internal and external systems as in the USOS).

This section addresses the USOS architecture first, followed by a discussion of ROS TCS.

5.4 USOS Passive Thermal Control System

Since temperatures vary drastically across the Space Station, thermal control requirements are different and unique to each location. Temperatures along the truss decrease as the distance from the modules increases because most of the heat is generated around the module area. Temperatures around this area can vary from -126 to 149 C (-195 to 300 F), while temperatures at the outer limits of the truss can vary from -184 to 149 C (±300 F). Passive thermal control is the first method evaluated when equipment or payloads need to be protected because it is less expensive and simpler than active thermal control.

5.4.1 Purpose

The PTCS is responsible for maintaining USOS structures and external equipment within an allowable temperature range. With no fluid interface, it isolates USOS elements from the external environment. PTCS components are designed to minimize maintenance and refurbishment.

5.4.2 USOS PTCS Components

The three components used in the PTCS are insulation, surface coatings, and heaters. These components are used to maintain temperatures within acceptable ranges based on the local thermal environment.

Multilayer Insulation: Multilayer Insulation (MLI) is used to control heat transfer rates and minimize temperature gradients. Just as home insulation prevents heat from entering or escaping, an MLI blanket performs the same function for the Space Station.

As shown in Figure 5-2, the MLI consists of several layers. Overall thickness varies from 3.2 to 6.4 mm (0.125 to 0.25 inch). A single aluminized outer cloth layer provides protection for the intermediate layers from atomic oxygen, meteoroids, or debris. The intermediate layers provide very efficient thermal radiation shielding. An aluminized inner layer provides flammability protection and also helps to protect the intermediate layers from damage during handling and installation. The MLI blankets are also designed to allow trapped gases to escape during launch. Improper venting of the blankets could result in inflation of the blankets causing them to come loose or damage themselves or the surrounding structure.

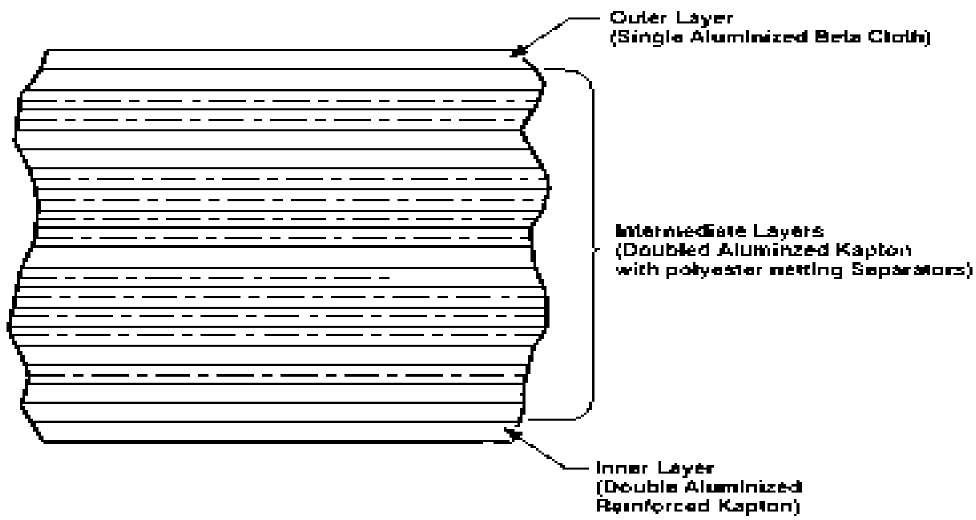


Figure 5-2. MLI design

MLI is used both inside and outside the modules, on truss segments, and on Orbital Replacement Units (ORUs). It is also used as a safety device to prevent crew contact with extreme temperatures.

Surface Coatings and Paints: Since thermal requirements vary from location to location, surface finishes vary throughout the Space Station. Thermal coatings and paints must be compatible with the environment and must be resistant to atomic oxygen and radiation.

The concepts of emissivity and absorptivity are critical to understanding surface finishes. All matter continuously emits electromagnetic radiation. Emissivity deals with the ability of an object to emit radiant energy (to radiate), while absorptivity describes the ability of an object to absorb radiant energy falling upon it. (Reflectivity is the opposite of absorptivity and should not be confused with emissivity.)

Emissivity and absorptivity values are defined in relation to a theoretical ideal called a "blackbody." If such a surface existed, it would emit the theoretical maximum amount of energy per unit area at each wavelength for any given temperature. It would also absorb all the radiant energy incident upon it. Such a surface would have emissivity and absorptivity values of 1.0, while a surface that did not emit or absorb any energy (a theoretically perfect reflector) would have values of 0.0. All real surfaces fall somewhere between these two ideals and are sometimes referred to as "gray bodies." Their emissivity and absorptivity values can be determined empirically and must be between 0.0 and 1.0.

The color of a surface may not indicate its overall capacity to absorb or reflect since radiant energy may be outside the visible spectrum. For example, snow is highly reflective of visible radiation but strongly absorbs infrared. Likewise, black objects absorb most visible light but may reflect other wavelengths.

Different types of finishes are used to provide various degrees of thermal control for equipment. By using coatings or paints with different emissivity or absorptivity characteristics, an ORU can either be "warmed" or "cooled" as required. For example, TCS radiators use high emissivity and low absorptivity coatings to help radiate excess heat to space.

The two types of finishes are anodized coatings which change the physical characteristics of the surface and paints which add a layer of material on top of the surface.

Table 5-1 shows typical surface finish properties.

Table 5-1. Typical surface finish properties

Surface finish	Use	Emissivity*	Absorptivity*
Sulfuric acid anodize	Primary and secondary structure	0.85	0.49
Z-93	EETCS radiators	0.91	0.15

*Values are typical at initial application; some degradation will occur over time.

Heaters: Electrically-powered heaters are used in locations where it is impossible or impractical to satisfy both high and low temperature requirements through the use of other PTCS or ATCS implementations. For example, heaters are used to prevent external TCS fluid lines from freezing in extremely cold environments and/or "no flow" conditions. There are over 300 heaters throughout the USOS on ORUs and modules.

Two types of heaters, operational heaters and survival heaters, are used on the USOS. Operational heaters keep a component at or above a minimum temperature while it is operating. Survival heaters prevent a component from damage by low temperatures while it is not powered.

Typical heater design includes a resistive wire element packaged in a high-temperature insulating material. Heaters are bonded with adhesive to the external surface of a module, the inside of an ORU, or wrapped around fluid lines. When electrical power is applied to the heater by a Remote Power Controller (RPC), the temperature of the element rises and heat is transferred by conduction to the component.

In order to maintain proper temperatures, sensing devices are placed near the heaters. Temperature sensors typically use a wire element that displays a linear resistance change for a corresponding temperature change. The resistance is measured as a voltage, which is calibrated to the properties of the sensor element. The voltage is detected by a Low Level Analog (LLA) card in a Multiplexer-Demultiplexer (MDM) and control of heaters is accomplished through software in the MDM. Heaters can also be controlled by thermostats, which regulate the temperature of a component independently. Typical heater control is illustrated in Figure 5-3.

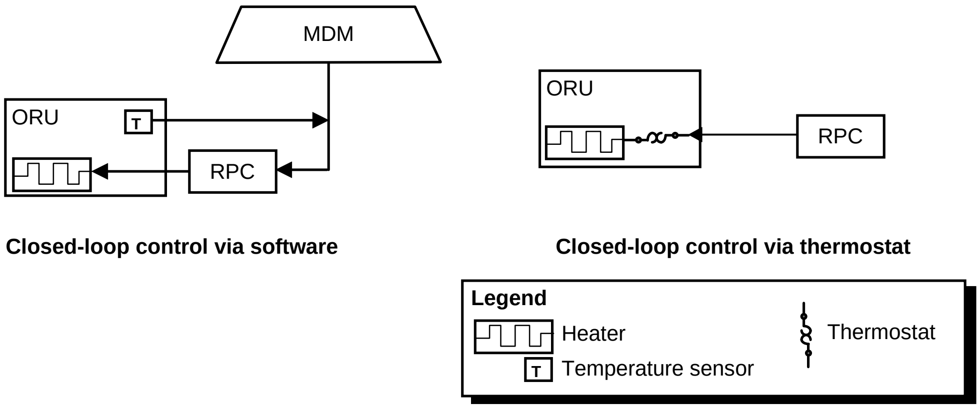


Figure 5-3. Typical heater control

Although heaters have interfaces with the Electrical Power System (EPS) and Command and Data Handling (C&DH), they are considered passive devices since they do not employ an active fluid.

Heat Pipes: An additional form of passive thermal control is the heat pipe. Heat pipes provide a near-isothermal method for transporting heat over short distances and have no moving parts.

A heat pipe operates by using the latent heat of vaporization of a working fluid (ISS applications use ammonia) to absorb heat at one end of a pipe and reject the heat into space at the other end. The working fluid is evaporated at the warm end of the pipe (where heat-generating equipment is located) and travels as vapor to the cool end (which is exposed to space). The fluid condenses and gives up its latent heat and returns as a liquid by capillary action. Several pipes are usually arranged side by side with a protective covering and structural attachments.

Heat pipes are used on the USOS to provide additional heat rejection for two Direct Current-to-Direct Current Converter Units (DDCUs) mounted on the Z1 Truss Segment and the two Node 1 Multiplexer/Demultiplexers (MDMs) mounted on the Pressurized Mating Adapter 1 (PMA-1). They are also used on the ROS (see Section 5.9).

5.5 USOS Active Thermal Control System

An ATCS is required when the environment or the heat loads exceeds the capabilities of the PTCS. As shown in Figure 5-4, an ATCS uses a mechanically-pumped fluid in closed-loop circuits to perform three functions: heat collection, heat transportation, and heat rejection.

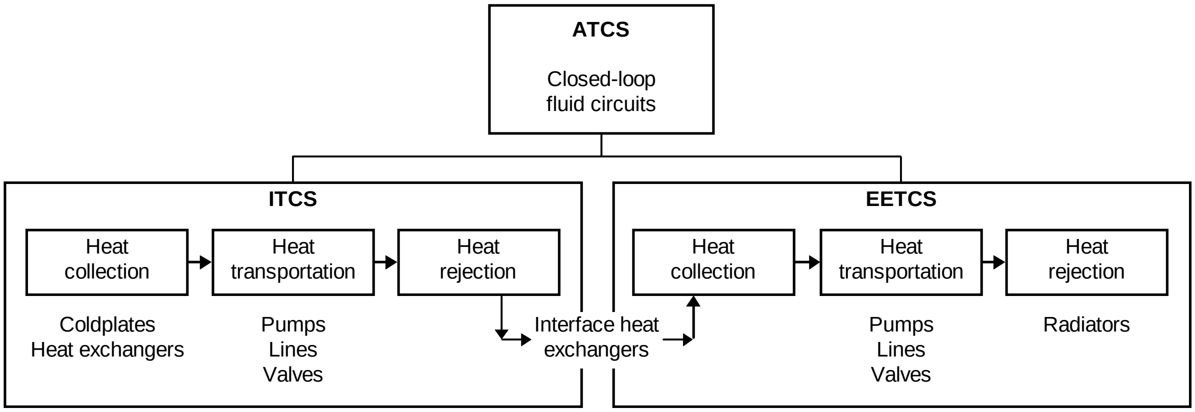


Figure 5-4. USOS ATCS architecture

5.5.1 Purpose

USOS ATCS is composed of internal systems that collect heat from equipment within elements and an external system that rejects the heat to space. The Internal Thermal Control System (ITCS) uses water, which is used because it is an efficient thermal transport fluid and is safe inside a habitable module. The Early External Thermal Control System (EETCS) uses anhydrous ammonia, which was chosen for its high thermal capacity and wide range of operating temperatures. The water and ammonia used in the ITCS and EETCS remain in a liquid state throughout the system.

The ITCS described in this training manual is based on the U.S. Laboratory Module (Lab). The ITCS for the U.S. Habitation Module (Hab), Japanese Experiment Module (JEM), Node 2, and Columbus Orbital Facility (COF) are similar.

5.6 Lab Internal Thermal Control System

All pressurized elements are outfitted with an ITCS. Some elements, such as Node 1, only contain some heat collection devices and fluid lines, while other elements have complete thermal loops.

5.6.1 Purpose

The purpose of the Lab ITCS is to maintain equipment within an allowable temperature range by collecting, transporting, and rejecting waste heat.

The Lab contains two independent loops, a Low Temperature Loop (LTL) and a Moderate Temperature Loop (MTL). This approach allows for segregation of the heat loads, simplifies heat load management, and provides redundancy in case of equipment failure (see Figure 5-5). The LTL operates at 4 C (40 F) and services systems equipment requiring low temperatures, such as the Environmental Control and Life Support System (ECLSS) Common Cabin Air Assembly (CCAA) and some payload experiments. The MTL operates at 17 C (63 F) and provides most of the cooling for systems equipment (i.e., avionics) and some payloads experiments.

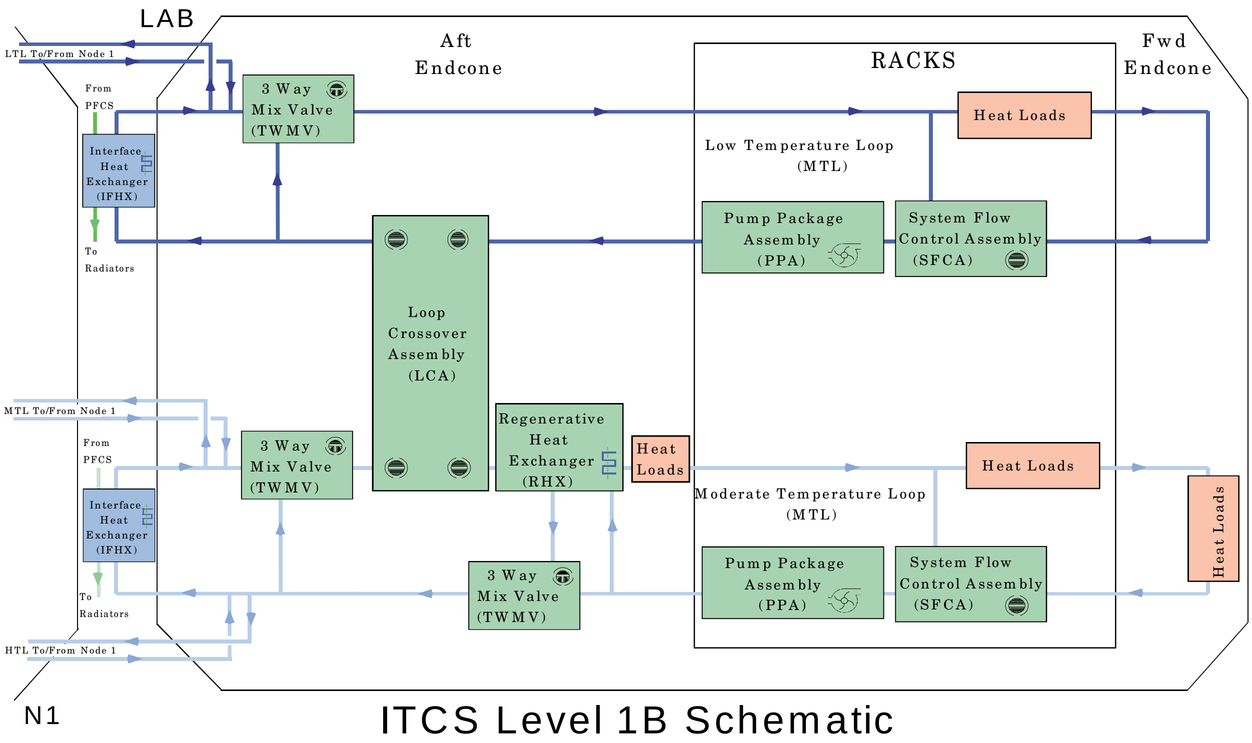


Figure 5-5. Lab ITCS

Normally, both ITCS loops operate independently in what is known as dual-loop mode. Under certain conditions (for example, a pump failure in one of the loops), the two loops can be connected. This configuration is known as single-loop mode and is used to prevent a loss of cooling to critical systems.

5.6.2 Lab ITCS Components

The components that make up the ITCS can be categorized by function into three major groups: heat collection ORUs, heat transportation ORUs, and heat rejection ORUs.

5.6.2.1 *Heat Collection ORUs*

In order to collect heat, the ITCS uses coldplates and heat exchangers. Most heat collection devices are located in the racks and others are located in the endcones.

Coldplates: Coldplates acquire heat from systems, avionics, and payload equipment. Heat-generating equipment is mounted to the surface of the coldplate where the heat is transferred by conduction to the coldplate surface. The heat is then transferred by convection to water flowing through the internally finned structure of the coldplate. There are no EPS or C&DH interfaces with coldplates.

Heat Exchangers: Heat exchangers are similar in function to coldplates, but provide a fluid-to-fluid transfer of heat. Heat exchangers are composed of alternating layers of finned passages that allow heat collected by another fluid to be transferred to the ITCS water. Heat exchangers may also be used to condense moisture from the air, as is the case with the Common Cabin Air Assembly (CCAA). There are no EPS or C&DH interfaces with heat exchangers.

5.6.2.2 *Heat Transportation ORUs*

Heat transportation components include pumps, lines, accumulators, filters, Quick Disconnects (QDs), and valves. These components move and direct the flow of water around the loops.

Pump Package Assembly: In order for the coldplates and heat exchangers to transfer their acquired heat to the water, the water must be circulating. A centrifugal pump, which is part of the Pump Package Assembly (PPA), provides this circulation. There is one PPA for each complete loop (see Figure 5-5).

Another important component of the PPA is the accumulator. It maintains inlet pressure to the pump and accommodates volumetric changes in a loop because of temperature variations. If a leak occurs, the accumulator can replenish lost water. Other PPA items include filters, a gas trap, a flowmeter, and temperature and pressure sensors. Control of the PPA is accomplished by software in the MDMs.

Lines: ITCS lines consist of rigid titanium and flexible Teflon tubing throughout the standoffs and endcones. Supply lines carry cooled water to the heat loads and the return lines carry warmed water from the heat loads to the Interface Heat Exchanger (IFHX). The lines are arranged so that water flows through the racks in parallel. LTL lines are wrapped with insulation since the water temperature is below the dewpoint of the air in the module. MTL lines are not insulated.

Tee sections are provided for each rack location and flex hoses are used to connect the tubing at the tee sections to the individual racks. The flex hoses plug into the base of the racks at the Rack Interface Panel (RIP) with self-sealing QDs. These QDs are used during rack changeout or leak isolation activities.

Valves: The following valves regulate and direct the flow of water through each loop. These valves are controlled by software in the MDMs and have manual override capability.

- Rack Flow Control Assembly (RFCA) - Regulates water flow through payload racks
- Manual Flow Control Valve (MFCV) - Provides fixed water flow through system racks (these valves are not software-controlled). Next to each MFCV is a Rack Standalone Temperature Sensor (RSTS) which is monitored by software in the MDMs.
- System Flow Control Assembly (SFCA) - Maintains a constant differential pressure between the supply and return lines. Includes a Shutoff Valve (SOV) to isolate the PPA.
- Loop Crossover Assembly (LCA) - Allows the MTL and LTL to be connected in series (single-loop mode) to avoid a loss of cooling if a PPA fails.
- Three-Way Mixing Valve (TWMV) - Maintains proper water temperature.

Another important ITCS ORU is the Regenerative Heat Exchanger (RHX). When the ITCS is in single-loop mode, the RHX warms LTL water before it flows through MTL lines to prevent condensation.

5.6.2.3 *Heat Rejection ORUs*

Interface Heat Exchanger: The Interface Heat Exchangers (IFHXs) are the heat-exchange interfaces between the two ITCS loops and the EETCS. The IFHXs are mounted on the aft endcone of the Lab external to the pressurized volume.

5.6.3 Lab ITCS Interfaces

The ITCS interfaces with three other systems

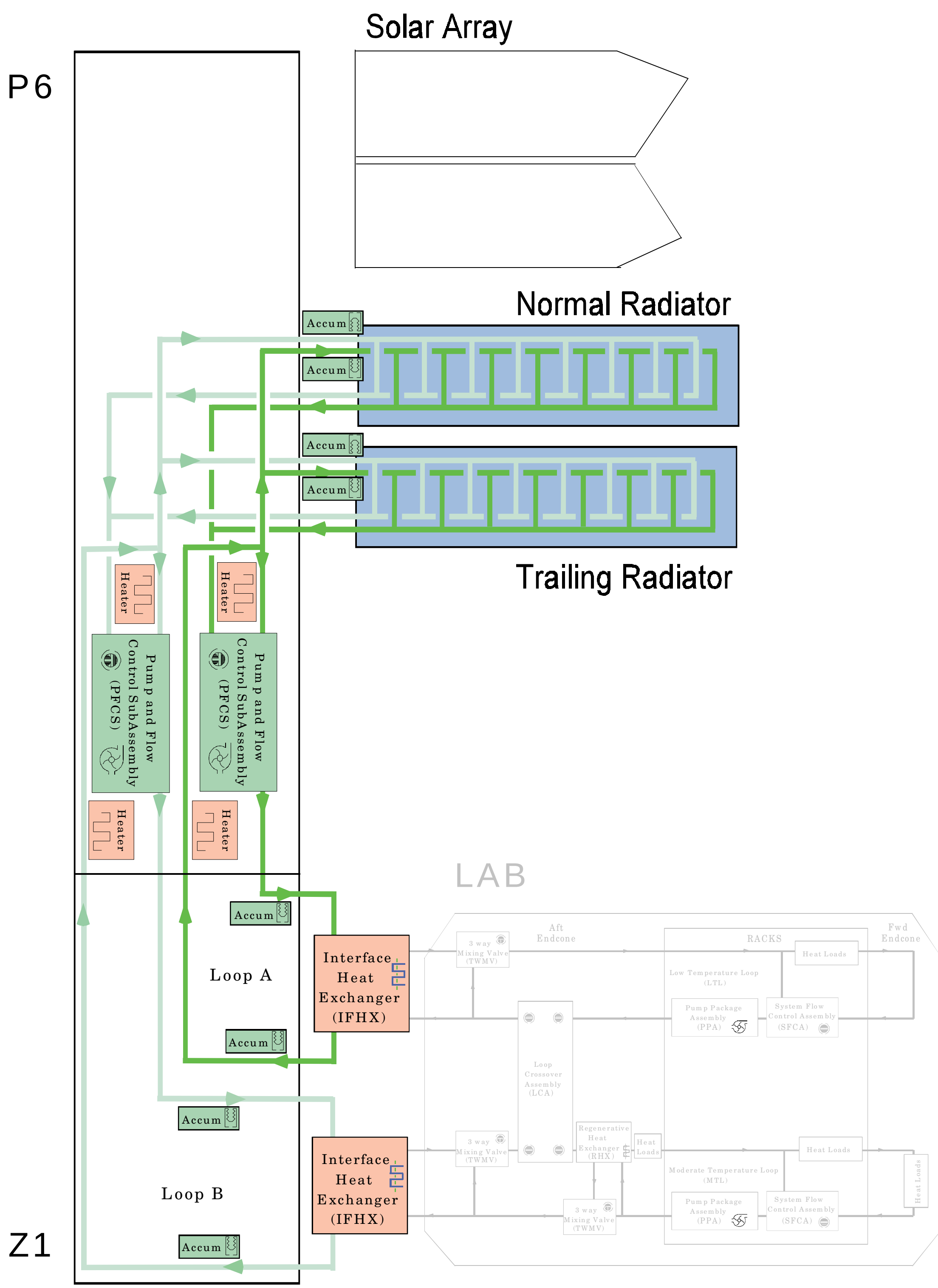
- EPS provides power to operate ITCS pumps and valves
- ECLSS-supplied nitrogen pressurizes the PPA accumulator
- C&DH MDMs provide commands and telemetry

5.7 USOS Early External Thermal Control System

Since the Lab becomes operational before the permanent External Thermal Control System (ETCS) is assembled, a temporary external cooling system is needed. External cooling from the Russian segment is not possible because there are no operational interfaces between the USOS and the ROS thermal systems. Instead, a modified version of the Photovoltaic Thermal Control System (PVTCS) called the Early External Thermal Control System (EETCS) acts as a temporary thermal system. ***The EETCS is needed until the components of the permanent ETCS are launched and activated***. Once the permanent ETCS becomes operational, the EETCS is deactivated. After deactivation, portions of the EETCS are used as components on PVTCS loops.

5.7.1 Purpose

The EETCS provides temporary heat rejection for the Lab using liquid ammonia to perform heat transfer. There are two identical loops (designated as Loop A and Loop B) operating at 2 to 5 C (35 to 41 F). Each loop is connected to an IFHX and both loops flow through the two radiators, providing a total of 14 kW of heat rejection for the Lab, Node 1, Mini-Pressurized Logistics Module (MPLM), and Airlock (Figure 5-6). Loop A interfaces with the LTL IFHX and Loop B interfaces with the MTL IFHX. All of the EETCS components are located outside the pressurized volumes to prevent crew contact with ammonia.



EETCS Level 1B Schematic

Figure 5-6. USOS Early External Thermal Control System

5.7.2 USOS EETCS Components

As with the ITCS, the major components of the EETCS may also be classified into three functional groups: Heat Collection ORUs, Heat Transportation ORUs, and Heat Rejection ORUs.

5.7.2.1 *Heat Collection ORUs*

Interface Heat Exchangers: The two Interface Heat Exchangers (IFHXs) are the only heat collection components in the EETCS. The IFHXs include a heat exchanger, a bypass valve, an isolation valve, a temperature sensor, and two pressure relief valves. While commands and telemetry are available for the temperature sensor and the bypass and isolation valves, the pressure relief valves operate automatically.

5.7.2.2 *Heat Transportation ORUs*

Heat transportation components include pumps, lines, accumulators, QDs, and flow control valves. These components move and direct the flow of ammonia around the loops.

Pump and Flow Control Subassembly: Circulation of the ammonia is provided by the Pump and Flow Control Subassembly (PFCS). The major components in the PFCS include two pumps, a Flow Control Valve (FCV), a Signal Conditioning Interface (SCI), a Local Data Interface (LDI), and an accumulator. Although the PFCS contains two pumps for redundancy, only one pump will be operated at a time.

The temperature of the ammonia is maintained by the FCV which mixes “cool” ammonia exiting the radiators with “warm” ammonia bypassed from the inlet to the radiators. While the FCV position is normally controlled by a closed-loop software algorithm, the capability for the crew or flight controllers to command the FCV to a specific position is also available. Control of the PFCS is accomplished via software in the Photovoltaic Controller Unit (PVCU) MDMs, which interface with the LDI. The PVCU software performs many system functions, such as loop leak detection, pump control, heater control, and loop temperature control.

The accumulator compensates for expansion and contraction of ammonia due to the temperature changes and keeps the ammonia in the liquid phase via the fixed charge of pressurized nitrogen gas on the back side of its bellows. In case of a leak, the accumulator also contains additional volume to replace lost ammonia. Other PFCS items include filters, a dual check valve, as well as pressure, temperature, and accumulator quantity sensors.

Other Heat Transportation Equipment: EETCS equipment is located on the P6 truss, the Z1 truss, and the Lab. The two radiators and two PFCSs are located on the P6 Truss. Insulated, stainless steel tubing carries ammonia between these components. The same type of tubing as well as two more accumulators are located on the Z1 Truss. Connections between segments are made with flex hoses and QDs. There are flex hoses and QDs between the P6 truss and Z1 truss, and between the Z1 truss and the Lab (IFHXs).

Each EETCS loop has in-line heaters wrapped around portions of the tubing on the P6 Truss. These heaters are used during low heat load conditions and are turned on and off by software while the system is operating to maintain the minimum operating temperature.

Trace heaters are located on the EETCS plumbing to prevent ammonia freezing during nonoperational periods. These heaters are thermostatically controlled (no software interfaces).

5.7.2.3 *Heat Rejection ORUs*

Radiators: Heat collected from the IFHX by the EETCS ammonia loops is radiated to space by two radiators. As shown in Figure 5-7, each radiator contains seven aluminum panels with stainless steel flow tubes or passages. The seven panels are hinged together and arranged in a folding array using manifolds and flexible hoses to connect the fluid path between the panels. Warm ammonia from both loops flow down one side of the radiator, through the panels where it is cooled, and then back up the opposite side. The complete seven-panel radiator array is considered an ORU.

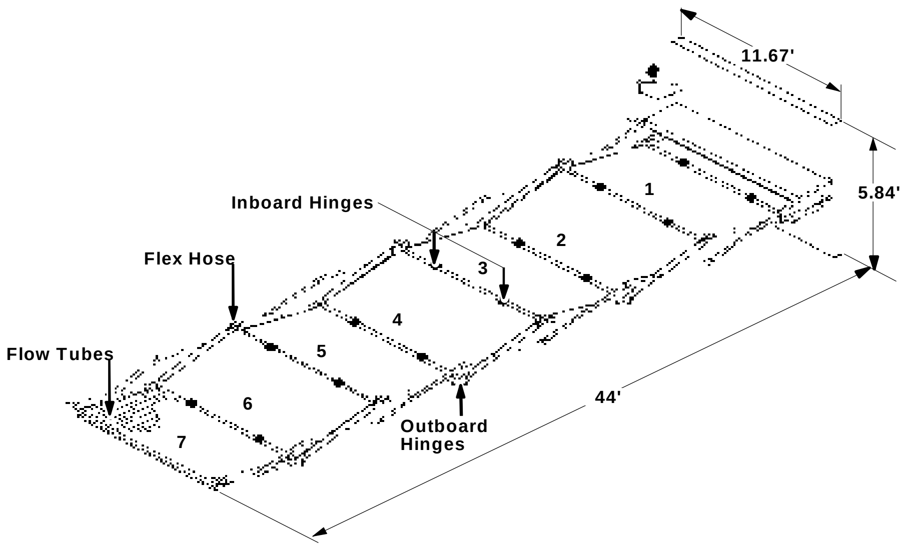


Figure 5-7. EETCS radiator

The two EETCS radiators can be deployed or retracted automatically through ground or crew commands or manually by an Extravehicular Activity (EVA) crewmember. When the radiator is retracted, a cinching mechanism holds it in the stowed position during non-operational periods and radiator replacement activities.

5.7.3 USOS EETCS Interfaces

The EPS provides power to each PFCS, the radiator deployment motors, and the in-line and trace heaters. The valves within the IFHX ORU also require power, but that power is supplied through the Node 1 MDMs instead of a direct interface with an RPCM. EETCS commands and telemetry are routed to ground workstations and crew laptops through the MDMs.

5.7.4 USOS External Thermal Control System

The ETCS replaces the EETCS and, once operational, continues the critical functions of collecting, transporting, and rejecting waste heat from USOS elements. Much like the EETCS, it is a mechanically-pumped, single-phase subsystem that also uses ammonia as a coolant. However, ***the ETCS is designed to handle the heat loads for the entire USOS at assembly complete***. The major differences between the temporary EETCS and the permanent ETCS are summarized in Table 5-2.

Table 5-2. EETCS/ETCS comparison

Temporary EETCS	Permanent ETCS
Heat Collection • Two IFHXs (Lab)	**Heat Collection** • 10 IFHXs – Lab (2), Hab (2), and Node 2 (6 total for Node 2, JEM, and COF) • Additional external equipment mounted on coldplates
Heat Transportation • Two loops operating at 771 kg/hr (1700 lb/hr) • One PFCS (two pumps) in each loop	**Heat Transportation** • Two loops operating at 3629 kg/hr (8000 lb/hr) • One Pump Module (PM) (one pump) in each loop
Heat Rejection • Two fixed radiators • Each is approximately 13 m (44 ft) long • Both loops flow through both radiators • Total heat rejection capability is 14 kW	**Heat Rejection** • Six moveable radiators • Each is approximately 23 m (75 ft) long • One loop flows through each set of three radiators • GNC software required to determine radiator position • Total heat rejection capability is 75 kW

5.8 USOS TCS Software

This subsection contains an overview of TCS software in the USOS.

5.8.1 Purpose

TCS software is used to control and monitor the system. Actions such as system startup, loop reconfiguration, and valve positioning for flow and temperature control are executed by the TCS software automatically or via commands from crew laptops or ground workstations. Telemetry from the various temperature, pressure, flow, and quantity sensors is monitored by TCS software and displayed on crew laptops or ground workstations. In addition, Fault Detection, Isolation, and Recovery (FDIR) software is used to monitor the performance of the TCS and, if there is a problem, alert the crew and controllers. In some cases FDIR software initiates recovery actions.

5.8.2 Architecture

Figure 5-8 shows how USOS TCS software is organized. At the top of the figure, it can be seen that the Command and Control (C&C) software resides in the Tier 1 MDMs. It is at this level the crew and controllers send commands to and view telemetry from the TCS. Software functions for the three C&C MDMs are redundant. In Tier 2, FDIR software is housed in the Internal Systems MDMs (INT MDMs) and the Node 1 (N1) MDMs (EETCS FDIR software also resides in the PVCU MDMs). The software in the Tier 2 MDMs processes commands from the C&C software, executes algorithms, and generates commands to the Tier 3 MDMs and certain TCS ORUs. Software functions for these MDMs are also redundant. The Tier 3 MDMs are the Laboratory Systems MDMs (LA MDMs) and the PVCU MDMs. The software in these MDMs interfaces directly with the ITCS and EETCS ORUs.

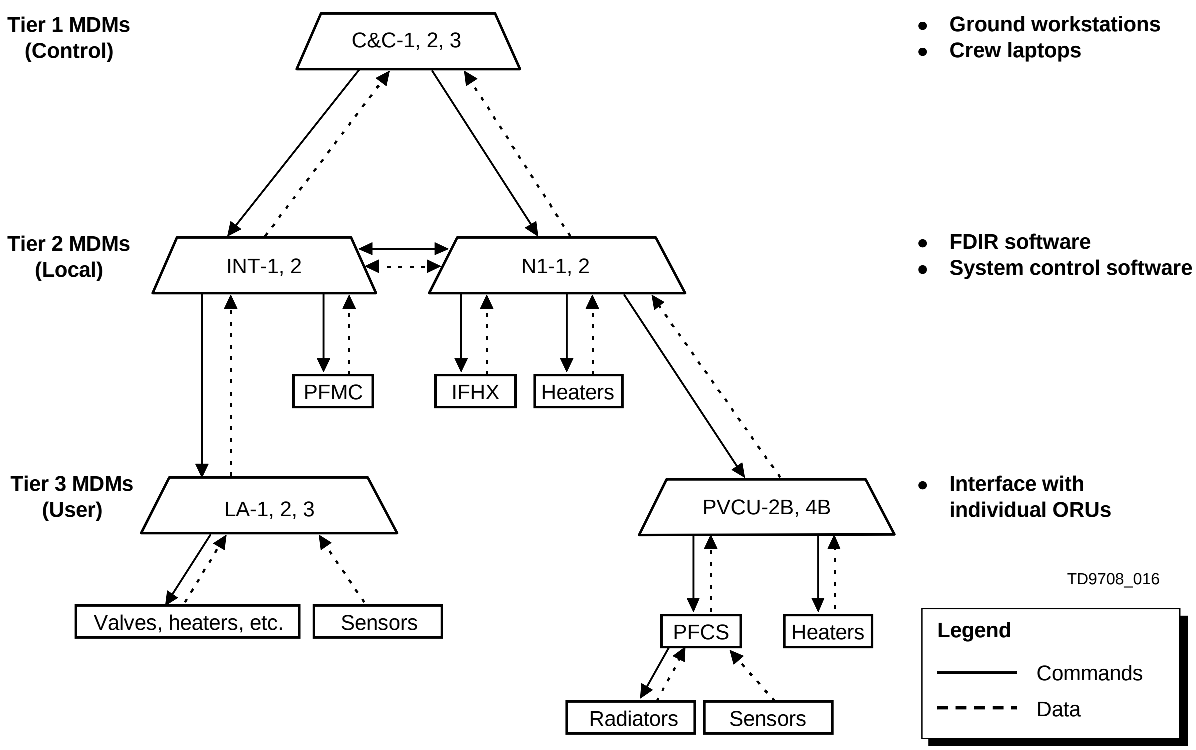


Figure 5-8. USOS TCS software architecture (Flights 5-A through 12-A)

Lab ITCS Software: Commands from ground workstations or crew laptops, as well as commands generated by C&C software, are passed by the C&C MDM to the active INT MDM (one MDM is active, with the other standing by to take over if necessary). Software within the INT MDMs processes the commands, executes algorithms, and generates commands to the LA MDMs and the Pump and Flow Control Subassemblies. The Pump and Flow Control

Subassembly process commands from the INT MDM and generate commands to the pump motors.

The LA MDMs process commands from the INT MDM, execute algorithms, and generate commands to Lab ITCS hardware. LA-1 interfaces with LTL hardware, LA-2 interfaces with MTL hardware, and all three LA MDMs interface with different RFCAs and RSTSs.

USOS EETCS Software: Commands from ground workstations or crew laptops, as well as commands generated by C&C software, are passed by the C&C MDM to the N1 MDMs. The two N1 MDMs control IFHX valves and process telemetry from the IFHX sensors. N1-1 interfaces with the IFHX in Loop A and N1-2 interfaces with the IFHX in Loop B. FDIR software also resides in the N1 MDMs.

The two PVCU MDMs control all of the remaining EETCS functions. The PVCU MDMs receive telemetry from and issue commands to the individual pumps and valves in the PFCS as well as the radiator deployment and retraction motors, PVCU-4B is primary, with PVCU-2B as backup. Note that the PVCU MDMs also perform FDIR.

5.9 ROS Thermal Control System

At assembly complete, the ROS will include the Functional Cargo Block (FGB), Service Module, Universal Docking Module, Research Modules, and Life Support Modules. All of these elements share common design characteristics.

5.9.1 Purpose

The purpose of the ROS TCS is to maintain equipment within an allowable temperature range by collecting, transporting, and rejecting waste heat from ROS pressurized elements. There are no interfaces between ROS TCS and the USOS TCS.

ROS pressurized elements are each outfitted with two internal and two external cooling loops. The coolant in each internal loop travels through the pressurized modules where it collects heat from systems equipment, avionics, and experiments. It then flows through an IFHX where the heat load of the internal equipment is transferred to the external system and is radiated and rejected to space.

The ROS TCS described in this manual is based on the FGB. TCS for the other ROS modules is similar.

5.9.2 FGB TCS Subsystems

FGB TCS is subdivided into two major groups: Passive TCS and Active TCS.

5.9.2.1 *FGB Passive TCS*

FGB passive TCS design is similar to USOS PTCS. FGB passive TCS relies on thermal blankets and surface coatings in order to maintain the temperatures of the structure and external equipment within allowable limits.

Shell heat pipes acquire heat from the internal loop and circulate ammonia around the exterior of the pressure shell. This prevents condensation by maintaining the temperature of the interior of the pressure shell above the dew point of cabin air. The shell heat pipes are used only for thermal conditioning and not for additional heat rejection capability.

5.9.2.2 *FGB Internal TCS*

FGB internal TCS (Figure 5-9) consists of two independent loops. The FGB internal TCS utilizes a single-phase water and ethylene glycol mixture to perform the three functions of heat collection, heat transportation, and heat rejection. ***Only one loop is in operation at a time; the second internal loop provides redundancy***. Nominal internal loop operating temperature is 15 to 35 C (59 to 95 F).

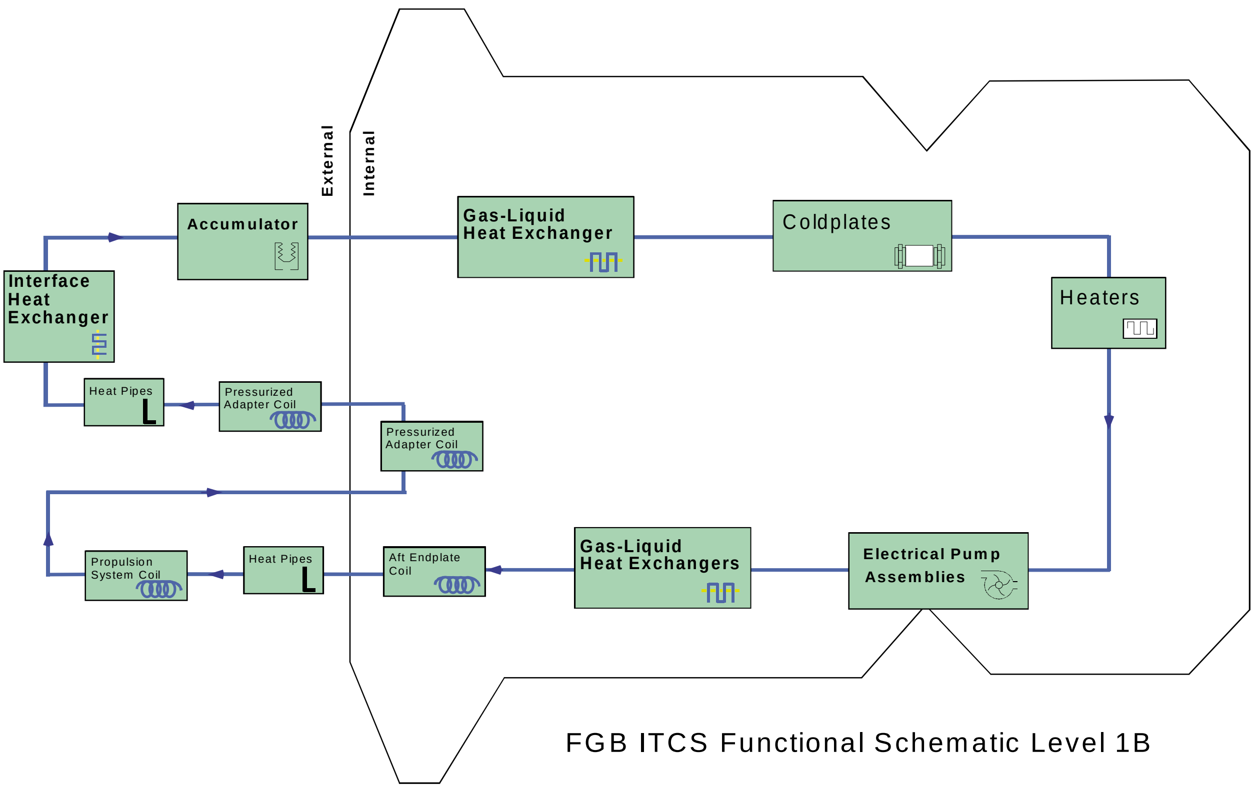


Figure 5-9. FGB internal TCS

In addition to fluid loops, a ventilation system is also a part of the FGB internal TCS. The ventilation system consists of fans mounted on gas-liquid (cabin air) heat exchangers, rigid and flexible distribution ducts, and portable fans. This function is analogous to the Temperature and Humidity Control (THC) System in the USOS ECLSS.

Heat Collection: The internal TCS loops acquire waste heat from coldplates and cabin air heat exchangers. Coldplates collect heat from most electronic equipment, and are similar in design and operation to the coldplates in the USOS. Air circulated through the cabin by the ventilation system picks up heat from the crew and other operating equipment. It then passes through the cabin air heat exchangers where its heat is transferred to the coolant.

Heat Transportation: Heat transportation components include pumps, an accumulator, lines, coils and valves. Each internal loop has two electrical pump assemblies, each containing two pumps. The electrical pump assemblies are replaceable on orbit and normally only one pump is active at a time. If a pump fails, software automatically starts a dormant pump. The accumulator maintains line pressure, accommodates volumetric changes in a loop caused by temperature variations, and replenishes the loop with coolant if a leak occurs. The lines include tubing, expansion joints, filters, fill and drain connections, and sensors. The internal loops are routed through coils in the aft endcone, the pressurized adapter, and propulsion units. Software-controlled heaters on the internal loops lines are used during periods of low heat loads.

Heat Rejection: The internal loop coolant transfers the heat it has collected to the external loop via an Interface Heat Exchanger (IFHX) mounted on the outside of the FGB. The IFHXs are similar in design and operation to the IFHXs in the USOS. Each internal loop flows through a separate IFHX. ***Temperature control of the internal loop is accomplished by regulating the temperature of the external loop.***

5.9.2.3 *FGB External TCS*

The FGB external TCS (Figure 5-10) consists of two independent loops. It uses a single-phase silicone fluid to perform the three functions of heat collection, heat transportation, and heat rejection. ***Only one loop is operating at a given time; the second external loop provides redundancy.***

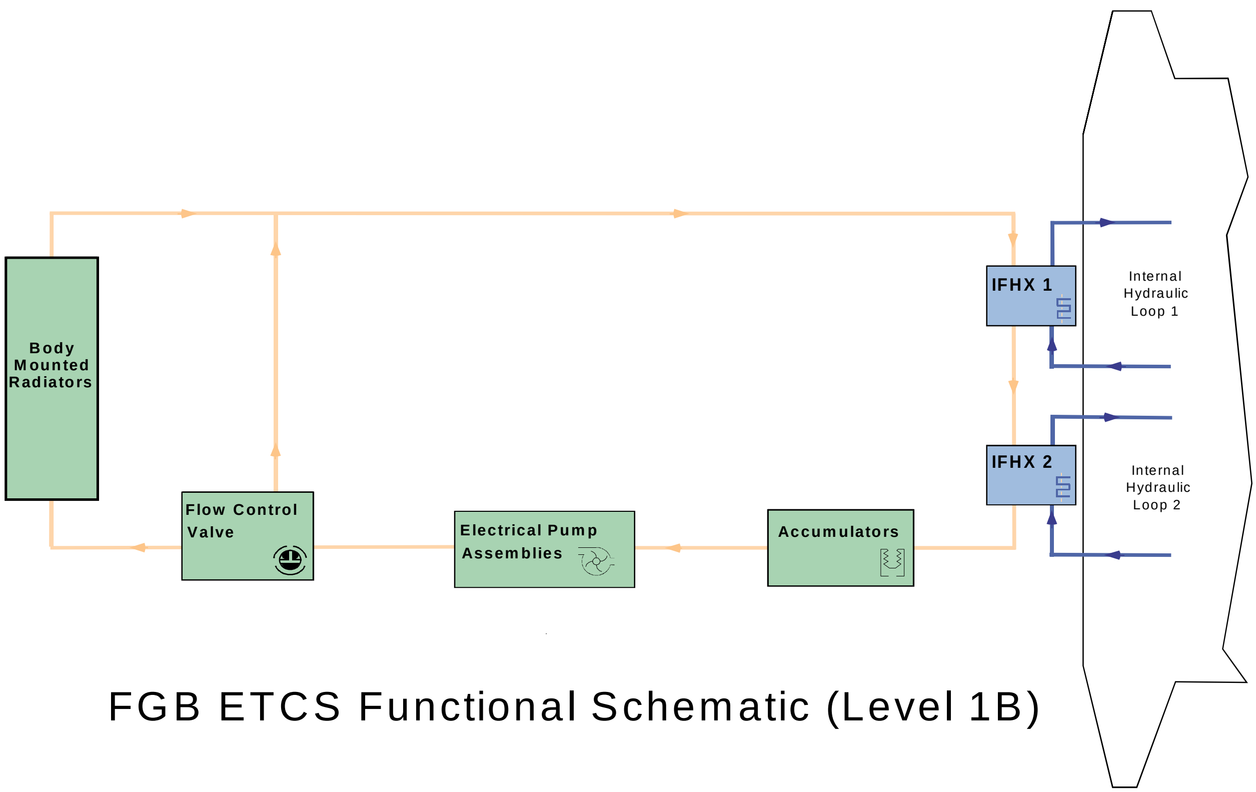


Figure 5-10. FGB external TCS

Heat Collection: The external loops acquire heat from the IFHXs. Both external loops flow through both IFHXs.

Heat Transportation: Heat transportation components include pumps, lines, and valves. Each external loop has three pump assemblies, each containing two pumps. Only one pump is active at a time. One of the pump assemblies in each loop is replaceable on orbit. If a pump fails, software automatically starts a dormant pump. A flow control valve modulates flow through the radiators in order to maintain a temperature setpoint (loop temperature is measured after the radiator flow and bypass flow have mixed). Software maintains a temperature range of 15 to 35 C (59 to 95 F). High internal heat loads will cause the internal coolant temperature to rise. The external system responds by allowing more coolant to flow through the radiators. During periods of low heat loads, the external system allows more coolant to bypass the radiators. The accumulators maintain inlet pressure to the pumps and accommodate volumetric changes in a loop because of temperature variations, and, if a leak occurs, the accumulators can replenish the loop with coolant.

Heat Rejection: Heat is rejected to space by body-mounted radiators (they are not deployable). There are 12 external radiator panels, each of which interfaces with both external loops. The radiators contain heat pipes which use ammonia as a working fluid. Heat is transferred from the external loops to the ammonia within the radiators and the ammonia is cooled by radiation to space.

5.9.3 Comparison of USOS and ROS TCS

Table 5-3 summarizes the differences between USOS TCS and ROS TCS.

Table 5-3. TCS comparison

USOS TCS	**ROS TCS**
• Habitable elements have ITCS • Shared temporary EETCS • Shared permanent ETCS	• Each habitable element has internal and external systems
USOS PTCS	**ROS PTCS**
• MLI, coatings, and heaters	• MLI and coatings • Shell heat pipes

Table 5-3. TCS comparison (continued)

USOS Lab ITCS	**FGB Internal TCS**
• Working fluid is water • Two operating loops (MTL and LTL) • Redundancy via connecting loops • Loop temperatures independently controlled	• Working fluid is water/glycol mixture • One operating loop (second loop is backup) • Redundancy via multiple pumps • Loop temp. determined by external system • Ventilation system (temperature and humidity control)

5.10 Flight-by-Flight Operations

TCS equipment is delivered over several flights. On the early flights, each ROS element is launched with a complete, independent TCS (passive and active systems). Components of the USOS EETCS are launched over three flights. The Lab arrives on Flight 5A with its ITCS and two IFHXs. Outfitting flights add racks and additional heat loads.

Later in the sequence, the permanent ETCS is assembled over several flights, and after Flight 11A it is activated and replaces the EETCS.

On Flight 10A, Node 2 is launched with its own ITCS and six IFHXs (two for its ITCS, and two each for the JEM and Columbus Orbiting Facility (COF)). The JEM and COF are launched later in the sequence, and the Hab is launched on Flight 16A with its ITCS and two IFHXs.

Table 5-4 summarizes the buildup of the Space Station TCS.

Table 5-4. TCS buildup

Flight	Element	TCS Components
1A/R	FGB	ROS TCS
2A	Node 1	Heaters and dry fluid lines
1R	Service Module	ROS TCS
3A	Z1 Truss	EETCS Z1 Accumulators, EETCS plumbing
2R	Soyuz	Permanent crew
4A	P6 Truss	Two radiators, two PFCSs, EETCS plumbing; checkout EETCS loops, activate EETCS loops

Table 5-4. TCS buildup (continued)

Flight	Element	TCS Components
5A	US Lab	ITCS, two IFHXs; connect utilities, prepare IFHXs, activate ITCS
6A	MPLM	Lab outfitting (racks and other heat loads), fill Node 1 lines with water (after orbiter departure)
7A	Airlock	High-pressure gas assembly (includes nitrogen for the Nitrogen Interface Assembly (NIA)), airlock heat loads
7A.1	TBD	Lab outfitting (racks and other heat loads)
UF-1	MPLM	Lab outfitting (racks and other heat loads)
8A	SO Truss	Parts of the permanent ETCS
UF-2	MPLM	Lab outfitting (racks and other heat loads)
9A	S1 Truss	Major components of permanent ETCS Loop A
9A.1	SPP	ROS TCS (CHRS)
11A	P1 Truss	Major components of permanent ETCS Loop B
10A	Node 2	ITCS, six IFHXs; connect utilities, prepare IFHXs, activate ITCS
1Ja	JEM	ITCS; connect utilities, prepare IFHXs, activate ITCS
UF-3	MPLM	Lab outfitting (racks and other heat loads)
14A	Cupola	Connect utilities, cupola heat loads
16A	Hab	ITCS; connect utilities, prepare IFHXs, activate ITCS
1E	COF	ITCS; connect utilities, prepare IFHXs, activate ITCS

5.11 TCS Summary

5.11.1 USOS PTCS Summary

The PTCS is designed to provide thermal control of USOS components via MLI blankets, surface coatings, and heaters. There are no active fluid components in PTCS devices.

5.11.2 USOS ATCS Summary

When the environment of heat loads exceeds the capabilities of the PTCS, an ATCS is required. An ATCS uses a pumped fluid to perform heat collection, heat transportation, and heat rejection. The working fluids in the USOS and ROS remain in a liquid state throughout the system.

5.11.3 Lab ITCS Summary

Water cooled by the IFHX enters the racks containing heat-generating equipment and payloads. Water passing through coldplates and heat exchangers collects the waste heat then exits the racks through the RFCAs or MFCVs. The cooling requirements of each rack are satisfied by the ability of the RFCAs to regulate flow through each rack. The water continues to the SFCA, which balances the ΔP between the supply and return lines, and on to the PPA. After passing through the PPA, the water continues back to the IFHX. The transfer of heat to the EETCS occurs in the IFHX. The TWMVs control the temperature of each loop.

Redundancy is provided by having two PPAs. If a PPA fails, the ITCS switches from dual-loop mode to single-loop mode. The LCA is part of the redundancy function since it allows the two loops to be connected.

5.11.4 USOS EETCS Summary

The EETCS provides temporary thermal control for the Lab, Node 1, MPLM, and Airlock prior to the activation of the permanent ETCS. Waste heat from the ETCS is collected at the IFHX. Circulation of the ammonia and regulation of the loop operating temperature are provided by the PFCS pumps and FCV, which are located inside the PFCS ORU. Ammonia, pumped by the PFCS through the radiator, is cooled by radiating its heat to space. The radiator has the capability to be remotely deployed and retracted.

Redundancy is provided by having two pumps in each PFCS. Both loops also flow through both radiators. Note that if an entire EETCS loop fails, the heat can still be collected from both internal loops by switching the ITCS to single-loop mode. Heat rejection would occur in the remaining IFHX.

5.11.5 USOS TCS Software Summary

TCS software is used to control and monitor the ITCS and EETCS, most of it automatically. Telemetry from sensors is monitored by TCS software and displayed on crew laptops or ground workstations. FDIR software is used to check the performance of the ITCS and EETCS and alert the crew and controllers if there is a problem.

5.11.6 ROS TCS Summary

The ROS TCS is based on the Mir space station and is functionally similar to USOS TCS. An internal TCS loop uses a coolant to collect heat generated by the crew and equipment. The warm coolant is pumped to the IFHXs where heat is transferred to the external system. The external loop circulates its operating fluid through radiators where the heat is rejected to space. There are two internal loops and two external loops for redundancy.

Questions

1. PTCS Multilayer Insulation (MLI) is analogous to
   a. An ammonia coldplate.
   b. The Interface Heat Exchanger (IFHX).
   c. A home's insulation.
2. Which of the following BEST describes surface coatings used throughout the Station?
   a. Must be resistant to atomic oxygen and radiation.
   b. Must be common throughout the Station.
   c. Must have an emissivity greater than 1.0.
3. The ITCS is responsible for
   a. Pumping ammonia coolant to the radiators.
   b. Rejecting waste heat from pressurized elements to the EETCS.
   c. Mixing the water leaving and bypassing the radiator to maintain the proper coolant temperature.
4. The ITCS provides which of the following to the IFHX?
   a. Heat collected from internal equipment.
   b. Cooled single-phase ammonia.
   c. Cooled two-phase water.
5. The EETCS provides
   a. Permanent thermal control for the Russian elements.
   b. Two-phase ammonia cooling.
   c. Temporary cooling for the Station until the ETCS is activated.
6. Which of the following statements is INCORRECT?
   a. The ETCS has larger radiators than the EETCS.
   b. The ETCS has two pumps per loop and the EETCS has one.
   c. The ETCS provides cooling to external components via coldplates.

7. The Interface Heat Exchanger (IFHX)

    d. Lies within the pressurized module.

    e. Is completely external to the module.

    f. Is part of the boundary between the inside and outside of the module.

8. The temperature of the ammonia in the EETCS loops

    a. Is not regulated.

    b. Is regulated via the rate of flow by the pump package.

    c. Is maintained by bypassing some of the ammonia around the radiators.

9. Which of the following statements BEST describes TCS software

    a. Resides primarily in the Tier 1 MDMs.

    b. Monitors and controls the system.

    c. Always requires crew or flight controller inputs.

10. The FGB ITCS is responsible for

    a. Pumping water/glycol to the radiators.

    b. Rejecting waste heat to the EETCS.

    c. Using both air and water/glycol to provide cooling.

11. The FGB ETCS

    a. Flows through both IFHXs.

    b. Has two loops operating simultaneously.

    c. Operates at a higher temperature than the FGB ITCS